MODELING OF FLUID FLOW INSIDE UMP'S FRANCIS TURBINE USING COMPUTATIONAL FLUID DYNAMICS (CFD)

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SUPERVISOR’S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

This project describes and explains the fluid flow conditions and parameters within a Francis Turbine with regards to each part of the turbine in contact with the working fluid and all working parts of the turbine. The process of obtaining the fluid flow condition and characteristic within the turbine is done by Computational Fluid Dynamics (CFD) simulation. Before CFD simulation is done, a model of the Francis needs to be selected as there are wide ranges of model ranging from conventional usage to demonstration purposes. Considering the availability of the turbine and data, UMP's Gunt Hamburg Demonstration Francis Turbine HM150.20 was selected. The project was then continued by referring to this model. The project was divided into 3 main parts that is experiment on the actual Francis Turbine in order to get real data which will then be used to validate the simulation data by the mean of comparing efficiency curve. The next part is Computer Aided Design (CAD) modeling based on the Gunt Hamburg Demonstration Francis Turbine HM150.20 dimensions and specifications obtained from the manufacturer and measurement on the actual turbine. The CAD modeling was done with consideration to the working parts of the turbine and external parts which are not bounded by the fluid flow region are placed with equivalent readout such as torque which is measured directly at the runner. The third part of the project would be the simulation by using CFD code. During this part, the constructed CAD model is subjected to boundary and flow conditions obtained from experiment and run to obtain the required data. After simulation is done by CFD code, the data obtained is validated by comparing the efficiency curve to verify that the simulation result is correct and fulfill the condition needed for analysis. The significance of the project is that it provides comprehensive and complete flow condition within UMP's Gunt Hamburg Demonstration Francis Turbine HM150.20 which can be used for further studies on the fluid flow inside the turbine and efficiency improvement for the turbine.

ABSTRAK

Projek ini menceritakan dan menerangkan keadaan pergerakan dan parameter bendalir di dalam “Francis Turbine” dengan perihal bahagian-bahagian yang berada dalam lingkungan bendalir dan bahagian operasi “Turbine” tersebut. Proses mendapatkan pergerakan bendalir dan karakteristik dilakukan melalui Pengiraan Bendalir Dinamik (CFD). Sebelum CFD dilakukan, model “Francis Turbine” harus dipilih terlebih dahulu kerana terdapat seleksi “Francis Turbine” yang besar dari jenis conventional ke jenis demonstrasi. Berdasarkan seleksi data dan “Francis Turbine” yang sedia ada, Gunt Hamburg Demonstration Francis Turbine HM150.20 UMP dipilih. Projek ini terbahagi kepada 3 bahagian iaitu experimentasi ke atas “Francis Turbine” bagi mendapatkan data yang akan digunakan bagi mengesahkan data yang bakal diperolehi dari simulasi. Kemudian process memodel “Francis Turbine” melalui Rekaan Bantuan-Komputer (CAD) berdasarkan spesifikasi yang diperoleh dari pengeluar dan ukuran yang diperolehi dari “Turbine” tersebut. Ketiga ialah proses simulasi melalui kod CFD. Ketika bahagian ini, model CAD yang dibina disimulasi dengan keadaan sempadan dan pergerakan bendalir yang diperoleh dari eksperimen untuk mendapatkan data yang deiperlukan. Selepas simulasi dilakukan oleh kod CFD, data melaui proses pengesahan melalui perbandingan bentuk lengkung keberkesanan simulasi dan eksperimen bagi memastikan ianya betul dan memenuhi keadaan diperlukan untuk analysis pergerakan bendalir. Signifikasi projek ini ialah ia membekalkan keadaan pergerakan bendalir yang komprehensif dan lengkap didalam Gunt Hamburg Demonstration Francis Turbine HM150.20 UMP yang boleh digunakan untuk kajian akan datang mengenai pergerakan bendalir di dalam “Turbine” disamping penambahbaikkan keberkesanan “Turbine” tersebut.

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LIST OF ABBREVIATIONS

η	Efficiency
2-D	2-Dimensional
3-D	3-Dimensional
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
F	Force
H	Head (Pressure)
K-ϵ	K-Epsilon
LBM	Lattice Boltzmann Method
LES	Large Eddy Simulation
M	Torque
n	Speed
P_{ab}	Braking Power
P_{hyd}	Hydraulic Power
RANS	Reynolds-Averaged Navier-Stokes
SPH	Smoothed Particle Hydrodynamics

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Francis turbine is a type of hydropower reaction turbine that contains a runner that has water passages through it formed by curved vanes or blades. The runner blades, typically 6 to 19 in number, cannot be adjusted. As the water passes through the runner and over the curved surfaces, it causes rotation of the runner. The rotational motion is transmitted by a shaft to a generator. It is an inward flow reaction turbine that combines radial and axial flow concepts where both concepts are flow are integrated into the turbine in order to make the water flow within the generator to be able to generate highly efficient rotation and energy transfer to the shaft and runners.

Francis Turbine is a hydropower reaction turbine that was discovered and invented by James Bicheno Francis in the year 1848. James Bicheno Francis was a British-American Engineer; he was born in Southleigh, Oxfordshire in England and immigrated to the United States at age 18. In 1834 he got a job at the Locks and Canal Company of Lowell, Massachusetts and became Chief Engineer in 1837 where he there remained at the company for his entire career.

It was in the years 1848 where he made his greatest achievement and contribution to the scientific society where he designed and created Francis Turbine which was a great improvement of the earlier turbines created by Jean-Victor Poncelet, Benoît Fourneyron, and Uriah Atherton Boyden to create a turbine with 90% efficiency which was far greater than what had been achieved by the earlier generation turbines.

He applied scientific principles and testing methods to produce the most efficient turbine design ever. More importantly, his mathematical and graphical calculation methods improved the state of the art of turbine design and engineering. His analytical methods allowed confident design of high efficiency turbines to exactly match a site's flow conditions. The Francis Turbine was considered to be a more efficient successor to the Boyden turbine. His analysis was proven as he opt to use skewed blade which is able to harvest energy from flowing water both radial and axial flow.

1.2 PROJECT OBJECTIVE

There are several objectives that are needed to be completed by the end of this project which are:

1. To create a complete, accurate and working 3D model of UMP's Francis Turbine in CAD.
2. To subject the constructed 3D model of UMP's Francis Turbine to boundary and initial condition such as the working environment of a Francis Turbine so that the fluid flow can be analyzed by a CFD code.
3. To study the flow characteristic of a Francis Turbine by means of analyzing the simulation result and interpreting them into their respective characteristic.

1.3 PROJECT SCOPE

This project concentrates it study on the flow analysis within the turbines runner under similar operating conditions of the actual turbine. Graphical and numerical simulation is done to determine and display the velocity profile and pressure distribution within the turbine runner and use the information to improve the efficiency of the turbine. The scopes of study are as follows:

1. CAD solid modeling (SOLIDWORK)
2. CFD analysis (COSMOS)
3. Turbine parameter modification.
4. Turbine efficiency improvement.
5. Validation study of efficiency and flow characteristic.

1.4 PROJECT BACKGROUND

The purpose of this project is to identify the pressure and velocity profile distribution within the runner of a Francis Turbine. From this project, we can observe and determine the pattern of velocity profile and pressure distribution by using CFD simulation program after the 3D modeling of the Francis Turbine is made.

Before the simulation is started, we need to determine the values of the Francis Turbine's working condition such as its pressure, mass flow rate etc. It is based on these reference values that we apply the values to the CAD model. Besides, our simulation is based on the design of the Francis Turbine. After finish the simulation, we need to devise a method to increase the performance and efficiency of the turbine.

Basically, the project revolves around the idea of investigating the effect and distribution of velocity profile and pressure within a turbine and based on the result obtained from the simulation to improve the turbine's efficiency.

1.5 PROBLEM STATEMENT

In turbines, one of the most important characteristic or properties of hydro powered turbines is the overall efficiency of the turbine which can be translated as how much of the original power of the flowing water is successfully converted or translated into electrical energy in case of damps. Turbines development have been mainly been focused on a creating a well rounded turbine with high efficiency value. However the actual efficiency and performance of this turbine may vary according to ambient conditions and working environment. It's based on this assumption that we are to analyze UMP's Francis Turbine to determine its rated efficiency.

The variation in the calculated efficiency compared to the theoretical efficiency of Francis Turbine occur caused by several factors which is different from the ideal condition of the turbine. Since turbines constructed by the supplier are practically identical, the factors that affect this efficiency difference surely must lay within the turbine's configuration e.g. the guiding vanes angle etc. Next is the existence of cavitations which reduces the turbine's overall efficiency and at the same time breaks or creates and propagates cracks at the runner's blade thus rendering the turbine defective.

When cavitations occur, the blades on the runner gather bubbles and pop. The pop of the bubbles break and indent the runner and guiding vanes that help the water or fluid move from the middle of the runner to the leading edge of the runner. The sound of cavitations is like pumping gravel through the volute or case. If the pump is experiencing cavitations, the ball valve is slowly turned clockwise to reduce input flow rate on the discharge side of the pump on a centrifugal pump and the gravel noise will reduce as a sign that the cavitations has been reduced. Cavitations will destroy the runner very fast by imploding bubbles on the runner and guiding vanes until the pump will not run anymore.

1.6 PROBLEM SOLVING

To study the flow characteristic of a Francis Turbine, several methods could be used. The easiest would be the path chosen in the project that is to attempt to model the fluid flow inside the turbine itself by mean of CAD modeling and CFD simulation. The method is the easiest and most effective since the variables and condition can be change at ease and the result from the modeling will be presented in both numerical and graphical method.

Several ways can be done to improve of optimize the efficiency of UMP's Francis Turbine; the simple method is to adjust the guiding vanes, so that the angle of entrance is changed and the cavitations is reduced or eliminated from the flow. The more complex method is modifying the turbines geometry and physical properties such as surface roughness, internal diameter, runner diameter etc. However trial and error method for each solution can be wasteful especially if done manually that is through fabrication process. So the best option for analysis is via simulation process which is more effective at testing and less costly. Simulation process which is proposed consist of the first part is the actual model simulation and based on the obtained results, certain parameters will be adjusted for optimum and maximum efficiency of the turbine.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research related to the current research done which is turbine, Francis Turbine, reaction turbine, cavitations, efficiency, hydro powered turbine, runner, guiding vanes, CAD, CFD, and velocity profile.

2.2 TURBINE

A turbine is a rotary engine that extracts energy from a fluid flow. Claude Burdin coined the term from the Latin *turbo*, or vortex, during an 1828 engineering competition. Benoit Fourneyron, a student of Claude Burdin, built the first practical water turbine.

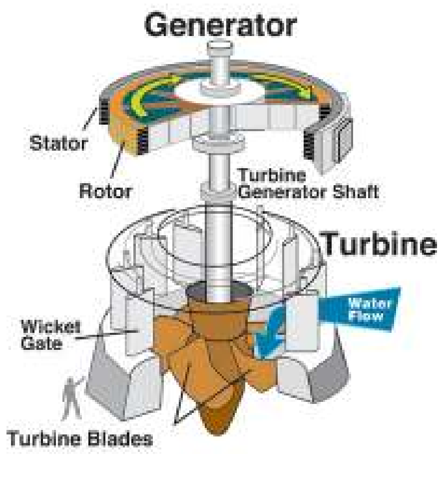

Figure 2.1: A basic electric generating turbine

The simplest turbines have one moving part, a rotor assembly, which is a shaft with blades attached. Moving fluid acts on the blades, or the blades react to the flow, so that they rotate and impart energy to the rotor. Early turbine examples are windmills and water wheels. Gas, steam, and water turbines usually have a casing around the blades that contains and controls the working fluid

2.3 FRANCIS TURBINE

Francis turbine is a type of water turbine that was developed by James B. Francis. It is an inward flow reaction turbine that combines radial and axial flow concepts. Francis turbines are the most common water turbine in use today. They operate in a head range of ten meters to several hundred meters and are primarily used for electrical power production.

Francis turbine was discovered by James Bicheno Francis in 848 by improving the earlier design of Benoit Fourneyron and Jean-Victor Poncelet to yield the most efficient turbine design ever with 90% efficiency.

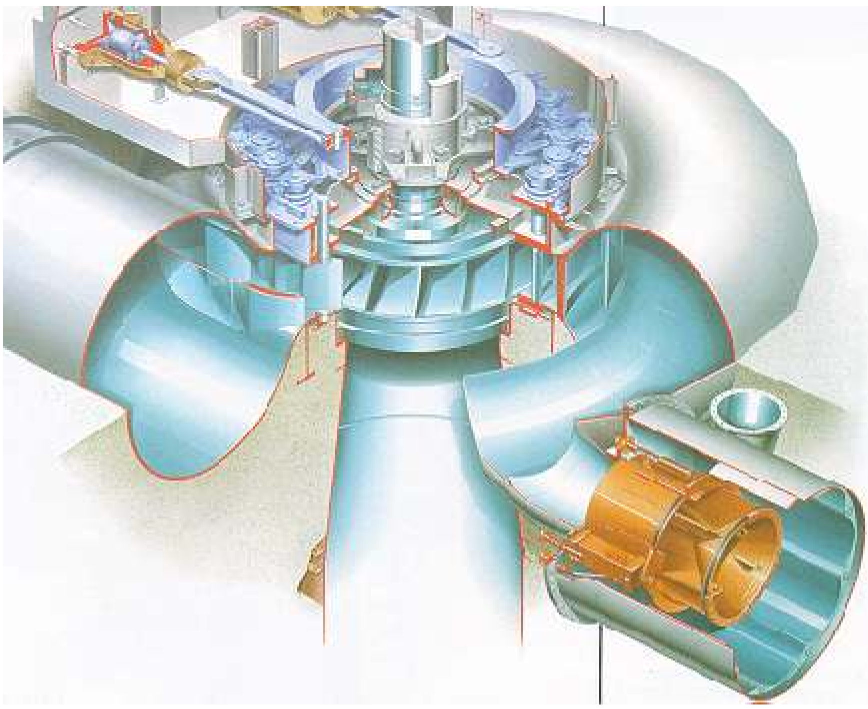

Figure 2.2: A large scale conventional Francis Turbine found in dams

2.4 REACTION TURBINE

These turbines develop torque by reacting to the fluid's pressure or weight. The pressure of the fluid changes as it passes through the turbine rotor blades. A pressure casement is needed to contain the working fluid as it acts on the turbine stage or the turbine must be fully immersed in the fluid. The body of the turbine contains and directs the working fluid and, for water turbines, maintains the suction imparted by the draft tube. Francis turbines and most steam turbines use this concept.

For compressible working fluids, multiple turbine stages may be used to harness the expanding fluid usually gas efficiently. Newton's third law describes the transfer of energy for reaction turbines. “Whenever a particle A exerts a force on another particle B, B simultaneously exerts a force on A with the same magnitude in the opposite direction. The strong form of the law further postulates that these two forces act along the same line. This law is often simplified into the sentence, "To every action there is an equal and opposite reaction."

2.5 CAVITATIONS

Cavitations are the formation of vapor- or gas-filled cavities in liquids. If understood in this broad sense, cavitations includes the familiar phenomenon of bubble formation when water is brought to a boil under constant pressure and the effervescence of champagne wines and carbonated soft drinks due to the diffusion of dissolved gases.

In engineering terminology, the term cavitations is used in a narrower sense, namely, to describe the formation of vapor-filled cavities in the interior or on the solid boundaries created by a localized pressure reduction produced by the dynamic action of a liquid system without change in ambient temperature. Cavitations in the engineering sense is characterized by an explosive growth and occurs at suitable combinations of low pressure and high speed in pipelines; in hydraulic machines such as turbines, pumps, and propellers; on submerged hydrofoils; behind blunt submerged bodies; and in the cores of vertical structures.

This type of cavitations has great practical significance because it restricts the speed at which hydraulic machines may be operated and, when severe, lowers efficiency, produces noise and vibrations, and causes rapid erosion of the boundary surfaces, even though these surfaces consist of concrete, cast iron, bronze, or other hard and normally durable material.

Both experiments and calculations show that with ordinary flowing water cavitations commences as the pressure approaches or reaches the vapor pressure, because of impurities in the water. These impurities, called cavitations nuclei, cause weak spots in the liquid and thus prevent it from supporting higher tensions. The exact mechanism of bubble growth is generally described by mathematical relationships which depend upon the cavitations nuclei.

Cavitations commences when these nuclei enter a low-pressure region where the equilibrium between the various forces acting on the nuclei surface cannot be established. As a result, bubbles appear at discrete spots in low-pressure regions, grow quickly to relatively large size, and suddenly collapse as they are swept into regions of higher pressure.

Figure 2.3: Example of cavitations in Francis Turbine

2.6 EFFICIENCY

The efficiency rated on a Francis Turbine is considered to be mechanical since the operating principle of a Francis Turbine includes the concept of simple mechanical structures such as the water hitting the runner will cause the runner to spin and at the same time rotating the shaft connecting the dynamo (in the case of a damp) to the turbine. This principle of energy transfer through the rotating of shaft is identified as mechanical hence evaluating the efficiency as mechanical.

In physics, mechanical efficiency is the effectiveness of a machine and is defined as:

$$Mechanical\ Efficiency = \frac{Work\ Output}{Work\ Input} \tag{2.1}$$

Mechanical Efficiency is the ratio of work input to work output. It is often expressed as a percentage. The efficiency of an ideal machine is 100 percent but an actual machine's efficiency will always be less than 100% because of the Second law of thermodynamics which states that the quality of energy will decay, eventually becoming heat. This means that some of the work put into the system is transformed (lost) into thermal energy (heat). In a mechanical system, friction is the most common cause of the work lost to heat.

The actual mechanical advantage of a system is always less than the ideal mechanical advantage due to these losses. Another way to express mechanical efficiency is it is the ratio of actual mechanical advantage to ideal mechanical advantage. In Francis Turbine case, the efficiency is the ratio of the power output or the braking force, to the water power entering the turbine.

2.7 RUNNER

In a Francis Turbine, the runner is the part of the turbine which is connected directly to the shaft of the turbine which is then normally connected to the dynamo. The runner consists of several small blades or fins which accepts and enhances the energy transfer from moving water to the shaft. The runner then, with the help of this blades spins based on the water flows energy which is successfully transferred to runner.

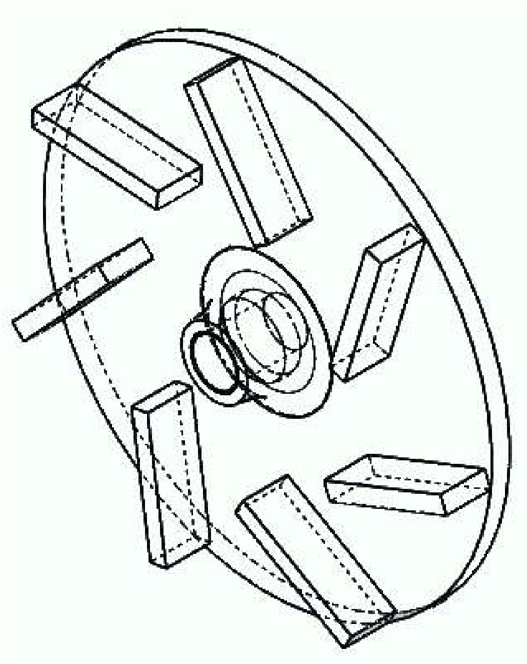

Figure 2.4: CAD model of the Gunt Hamburg Francis turbine runner

Since a Francis Turbine is inward flow reaction turbine, the runner is located at the centre at the turbine with a small cylindrical rod with curved sides at the very centre of the turbine which helps the water flow out of the turbine after their energy is transferred via the runner to the shaft. The water usually enters the runner at an angle somewhat tangential to the blades on the runner to gather the most energy from the flowing water. The runner of a Francis Turbine is said to be the most efficient turbine design up to date.

2.8 GUIDING VANES

The guiding vanes of a Francis Turbine are curved aerofoil-like parts of the Francis Turbine which normally placed at a certain distance away from the runner and consist of several parts which surrounds the runner. These vanes are used mainly for two reasons. The first is to guide the flowing working fluid to the runner and to control the angle of entrance so that cavitations will be reduced or eliminated.

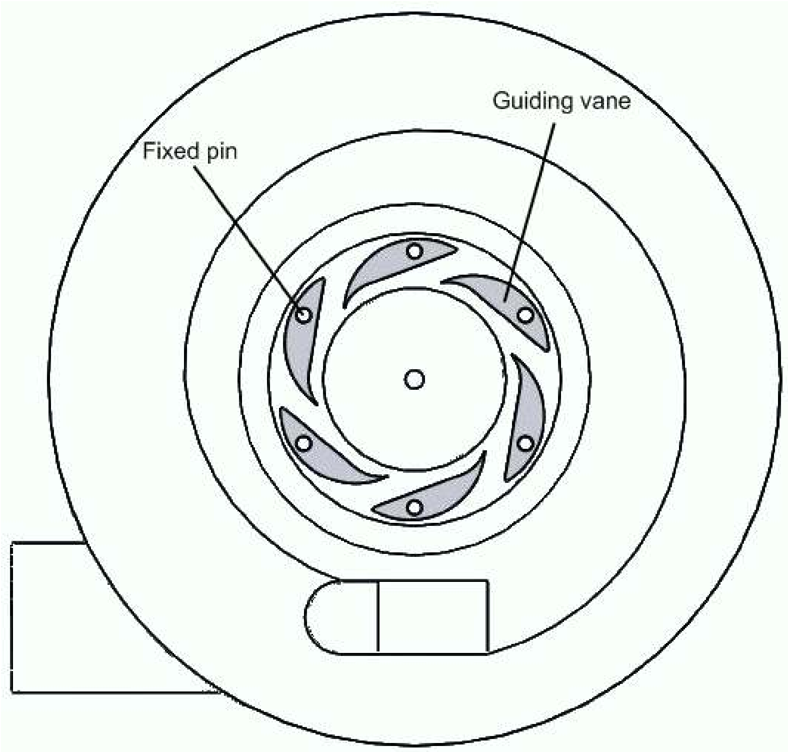

Figure 2.5: CAD model of the Gunt Hamburg Francis turbine guiding vanes and its position on the Francis Turbine

The vanes are placed so that the flowing water which enters the turbine is redirected into the passage created by the vanes. Water that flows within the Francis Turbine are classified as turbulent which mean their flows are highly unsteady and violent. It is the characteristic of this flow that cause the water inside the turbine to